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NUTRIENT PRODUCTIVITY STUDIES IN SAN FRANCISCO BAY

Central Pacific Basins
Water Pollution Control Project
Technical Report No 65-1

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE
Public Health Service, Region 1X
San Francisco, California

July 1965

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NUTRIENT - PRODUCTIVITY STUDIES

IN SAN FRANCISCO BAY

by

Richard C. Bain, Jr.
James C. McCarty

Abstract

This report presents data and relationships observed in a study of the waters of north San Francisco Bay, San Pablo Bay, Suisun Bay and the western extreme of the Sacramento - San Joaquin Delta, California. Samples were collected on eight morning cruises from May to September 1964 on a high slack tide. Biological and nutrient analysis of the samples include phytoplankton productivity using C-14, algal identification and population counts, the nitrogen series, dissolved and total phosphorus. Other determinations include temperature, pH, alkalinity, suspended solids, chlorosity, and dissolved silica. Phytoplankton productivity and nutrient dynamics through the study period and the study area are characterized.

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INTRODUCTION

Authority

The Federal Water Pollution Control Act, as amended, (33 U.S.C. 466 et seq.) delegates broad responsibilities for water pollution control to the U. S. Department of Health, Education and Welfare (DHEW). As a result of these responsibilities, the DHEW, Public Health Service, is interested in federal water resources development activities and in preserving the waters affected by these activities for future beneficial uses. Recent studies by the Division of Water Supply and Pollution Control, Public Health Service (DWS&PC, PHS) Region IX, San Francisco (1) have resulted in concern over the possibility of accelerated eutrophication of San Francisco Bay and contiguous waters as a result of increased waste discharges and reduced freshwater inflow. This study of existing conditions will provide background information for future pollution control activities related to the disposal of wastes containing plant nutrients into the Bay system.

Purpose and Scope

The purpose of this study is to define a seasonal period of maximum phytoplankton activity in an estuarine environment by measuring physical, chemical, and biological changes. The study encompasses the San Francisco Bay estuary from the Golden Gate to the western extreme of the Sacramento - San Joaquin River Delta. Additional control samples were collected from offshore waters in the Pacific Ocean. Eight sampling cruises were completed between May 7 and September 1, 1964.

Acknowledgments

This study was a cooperative effort between the University of California, Sanitary Engineering Research Laboratory (SERL) Richmond Field Station, Richmond, California and the U. S. Public Health Service, DWS&PC, Region IX, San Francisco, California.

The following University personnel have made major contributions to this study:

Dr. Robert E. Selleck, Assoc. Professor of Sanitary Engineering

Dr. David Jenkins, Chief Chemist, SERL and Asst. Professor of Sanitary Engineering

Steven Chaum, Laboratory Technician, Boat Operator, Student

The PHS Robert A. Taft Sanitary Engineering Center (RATSEC), Cincinnati, Ohio, conducted the chemical analysis of nutrient materials. The following SEC personnel were particularly helpful in setting up the PHS portion of the study and in coordinating the analytical work in Cincinnati:

Dr. William M. Ingram, In Charge, Biological, Chemical, and Oceanographic Activities

Dwight Ballinger, Chief Chemist, Biological, Chemical, and Oceanographic Activities

The U. S. Coast Guard, based on Yerba Buena Island in San Francisco Bay, collected the ocean samples. Their cooperation is greatly appreciated.

SUMMARY AND FINDINGS

Summary

1. As a cooperative venture, the University of California Sanitary Engineering Research Laboratory (SERL) and the U. S. Public Health Service (WS&PC Region IX) conducted a nutrient - productivity study of the San Francisco Bay estuary.

2. The study area included two ocean stations and 13 estuarine stations from the Golden Gate to the Antioch Bridge.

3. The time of the study was from May through September 1964.

4. Cruises were generally scheduled every two weeks and samples were collected on a high tide slack.

5. Nutrient analyses included the nitrogen series and total and total dissolved phosphorus.

6. Productivity measurements were carried out using carbon 14 in the laboratory.

7. Other determinations included water temperature, chlorosity, dissolved silica, pH, alkalinity, suspended solids, and phytoplankton population identified and enumeration.

Findings

1. Water temperature varied from less than 12°C to more than 22°C and increased riverward and through the study period with a drop observed on the last cruise.

2. Chlorosity varied from nearly 19 grams per liter in the ocean to less than 1 gram per liter at the Antioch Bridge. Chlorosities increased in Suisun Bay and the western Delta toward late summer because reductions in fresh water inflow resulted in a further intrusion of saline waters.

3. Phytoplankton populations and productivity were highest in the Suisun Bay area and lowest in north San Francisco and San Pablo Bays.

4. Phytoplankton populations and productivity increased approximately ten fold between early May and mid July at Suisun Bay and western Delta stations.

5. Nitrate - nitrogen, dissolved phosphorus, and dissolved silica concentrations declined to low levels in Suisun Bay between May and July.

6. Difficulties were experienced in the analyses of certain nitrogen and phosphorus forms. Variations in salinity and turbidity within the study area or the sample preservation techniques may be responsible. As a result, studies have been initiated to determine the accuracy, reproducibility and statistical variation of available analytical and preservation techniques for estuarine waters.

DESCRIPTION OF STUDY

Study Area

The study area encompasses the north San Francisco Bay estuary from the Golden Gate Bridge on the west to the western edge of the Sacramento - San Joaquin River Delta on the east. (Figure 1). Thirteen sampling locations were selected in north San Francisco Bay, San Pablo Bay, Suisun Bay and in the western Delta. Sampling station locations are described in Table 1 and shown on Figure 1. Two additional sampling stations were located in the Pacific Ocean due west of the Golden Gate Bridge. Most of the sampling locations are identical to those used by the University of California, SERL, in their comprehensive study of San Francisco Bay (U.C. Bay Study) and reference is made to their reports (2) for detailed station descriptions.

TABLE 1

Sampling Station Locations

Station	Location
1	Central Bay #6, U.C. Bay Study
2	North Bay #1, U.C. Bay Study
3	North Bay #4, U.C. Bay Study
4	North Bay #9, U.C. Bay Study
5	San Pablo Bay #4, U.C. Bay Study
6	San Pablo Bay #6, U.C. Bay Study
7	San Pablo Bay #9, U.C. Bay Study
8	Suisun Bay #1, U.C. Bay Study
9	At Dolphin in central portion of Grizzly Bay*
10	Between buoys #16 and #17 in main channel of Suisun Bay*
11	Off buoy #19 in main channel of Suisun Bay*
12	Suisun Bay #7A, U.C. Bay Study
13	Suisun Bay #10, U.C. Bay Study
A	Ocean 5 miles west of Golden Gate Bridge
B	Ocean 15 miles west of Golden Gate Bridge

* Refer to U.S. Coast and Geodetic Survey Chart 5534 (Suisun Bay) 27th Ed., March 16, 1964.

Study Period

The study period extended from May 7 through September 1, 1964. The spring - summer period was selected for intensive study because phytoplankton populations have been noticeably larger at this time of the year.

A two week interval between sampling cruises was selected because this approximates one-half lunar month and allows each sampling cruise to be conducted under similar tide and light conditions. Each cruise consisted of two separate sampling runs; usually the Suisun Bay - Western Delta samples were collected the first morning and San Pablo and north San Francisco Bay samples the next morning. Ocean samples were collected separately by the U.S. Coast Guard.

The cruise dates are listed in Table 2. Nearly one month separates cruise 7 from cruise 8. This departure from the usual two week interval was considered acceptable because the peak phytoplankton activity had passed.

TABLE 2

Sampling Cruise Schedule

Cruise	Bay	Ocean
1	May 7,8	
2	May 20, 22	May 20
3	June 2, 3	
4	June 17, 18	June 17
5	July 2, 3	
6	July 16, 17	July 15
7	August 1, 3	
8	August 31, September 1	

Sampling Methods

All Bay sampling cruises were made in a small cabin cruiser owned and operated by the University of California. This boat was capable of following slack tide sampling schedules under most weather conditions. Samples from all stations were collected at or near the same lower - high slack tide and before noon whenever possible.

Surface samples were collected with a plastic bucket dipped below the surface to avoid floating materials. Three bottles were filled at each station. Samples for productivity and nutrient analyses were

placed in 1 liter polyethelene containers, and phytoplankton samples were placed in 400 ml glass jars containing 40 ml neutral formalin. The nutrient samples were fixed with 1 ml concentrated H_2SO_4/liter to arrest bacteriological activity.

Several samples were collected at mid-depth at stations 4, 7, 8, and 11. A weighted Kemmerer sampler was used.

Air and water temperature, time, and general climatic conditions were recorded for every sample. All samples were taken directly to the University of California, Sanitary Engineering Research Laboratory (SERL) in Richmond, California, on completion of each morning cruise.

Sample Analyses

The sample were handled in one of four ways depending on the type of analysis to be performed.

Productivity analyses. An unpreserved surface water sample was used for the productivity determination. The productivity analysis provides a measure of phytoplankton photosynthetic activity.

In the process of photosynthesis, plants are able to capture solar energy (or other light energy of suitable wavelength) and utilize CO_2, water and other inorganic constituents (phosphorus, nitrogen, and various trace materials) to produce energy - containing organic material. In this process, oxygen is released to the environment. Respiration continues under light or dark conditions and involves the conversion of organic material in the presence of oxygen to CO_2 and water.

There are two principle methods of measuring phytoplankton productivity, one by measuring oxygen production, the other by measuring carbon uptake. In this study, carbon uptake was measured using carbon-14, a radioactive isotope, as a tracer. The method used was one developed by Dr. David Jenkins (3) of SERL. Briefly, the analytical procedure includes six phases: inoculation, incubation, filtration, desiccation, combustion and counting. These steps are described below:

1. Inoculation: Two 120 ml glass bottles, one clear, one taped and painted to exclude light, are filled from a sample bottle and inoculated with a known amount of standardized $Na_2C^{14}O_3$ solution.

2. Incubation: The bottles are placed in an illuminated water bath held at 20° centigrade under non-limiting light conditions (1400 ft-candles) for from 4 to 8 hours.

3. Filtration: Each sample filtered through a Whatman GF/C glass fiber filter.

4. Desiccation: The filter containing silt, detritus and phytoplankton from the incubated sample is thoroughly dried over silica gel.

5. Combustion: Each dried filter is heated to 700° centigrade in a furnace supplied with dry oxygen. In the pressence of heated catalysts, radioactive phytoplankton cell material is converted to $C^{14}O_2$. This gas is collected in CO_2 absorption tubes containing 2 exthoxyethanol and 2 ethanolamine protected by a safety trap.

6. Counting: The absorbed C^{14} is measured with a liquid scintillation counter and the results used to determine the total carbon synthesized by phytoplankton during the incubation period.

The light and dark bottles described in Step 1 provide a measure of gross productivity. The measured carbon 14 uptake from photosynthesis and adsorption on the bottle wall (the latter provided by the dark bottle uptake) is used to compute the total carbon fixation considering the ratio of radioactive carbon and total available carbon in the incubated sample.

Step 5 is necessary prior to counting because of the large quantity of solid silt particles in the samples. Direct counting of the filter results in errors from self-absorption and back-scattering by the low energy Beta emmissions of carbon-14. Other analyses performed in the laboratory in conjunction with the productivity determination include pH and alkalinity. Alkalinity provides a measure of the available carbon in the sample.

Nutrient analyses. Analysis of the nitrogen series (organic-N, NH_3-N, NO_2-N, NO_3-N) and of dissolved and total phosphorus were performed in Cincinnati, Ohio by the USPHS, Robert A. Taft Sanitary Engineering Center. One liter samples fixed with 1 ml H_2SO_4 were packed in polyethelene containers and air mailed to RATSEC. The nitrogen and total phosphorus tests were performed on these samples. Samples for dissolved phosphorus analysis were filtered and fixed with acid shortly after collection and packed separately in 100 ml containers prior to shipment to the laboratory.

The methods used in these tests were as follows:

Organic Nitrogen: Microkjeldahl, with final ammonia determination by Nessler reagent. The ammonia-nitrogen was deducted from the total Kjeldahl-nitrogen to obtain the organic-nitrogen concentration. Reference, Standard Methods, 1960, Page 182-183. (4)

Ammonia Nitrogen: Direct nesslerization. Reference, Standard Methods, 1960, page 173. (4)

Nitrite Nitrogen: Diazotization Method, Reference, Standard Methods, 1960, page 180. (4)

Nitrate Nitrogen: Jenkins Brucine Method. Analytical Chemistry, 1964. (5)

Phosphorus, Total and Dissolved, Standard Methods, 1960 page 202. (4)

Phytoplankton analysis. Permanent slide mounts were prepared from each formalin preserved sample. The samples were decanted, centrifuged, and washed repeatedly before the algal residue was mounted on a slide, in accordance with methods developed by the University of California, San Francisco Bay Study (2). These slides were counted at 440 X and the dominant algae (mainly diatoms) identified to genea. Comparative identification and counts were also obtained from several samples using the Sedgewick Rafter slide technique (4) as modified by PHS (6).

Other tests. Chlorosity and dissolved silica analyses were conducted by SERL during the interval between cruises. Suspended solids determinations were made on 5 samples from cruise 6. The methods used were as follows:

Chlorosity:* Standard Methods, 1960, page 79 (4)
Dissolved Silica: Standard Methods, 1960, page 228 (4)
Suspended Solids: A Comprehensive Study of San Francisco Bay (Annual Report 1962-63) page I-5 (2)

Limitations of Analyses

The results of this study will be more meaningful if the limitations of some of the methods are understood.

Productivity was measured in the laboratory on unstirred samples supplied with artificial light at 20° centigrade. Every sample was treated in the same manner to provide a common basis for comparison and should not be confused with in-situ values. Turbidity, depth, mixing and other light-limiting effects in the estuary are discounted in the laboratory. The test is, in essence, a measure of the production potential of the algae captured in the bottle (ie a productivity index).

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* As defined in The Oceans, Sverdrup, et al, 1942 Prentice Hall, page 52. Chlorosity is the property corresponding to chlorinity expressed as grams per 20°C liter.

The algal population are indicative of the larger diatoms and total biomass but do not reflect a high number of smaller organisms. The reported diatom populations (Appendix A) apparently do reflect the relative population density from one area or cruise to another. Only diatom genera are reported; however other algal phyla were found by different biologists using the Sedgewick Rafter technique.

Organic nitrogen measurements are not necessarily related to phytoplankton cell material. Discharges in Suisun Bay include a pulp mill, chemical plant, and refinery wastes as well as domestic sewage. The Sacramento and San Joaquin Rivers carry organic material from the peat soils of the Delta. As a consequence, the organic nitrogen values from Suisun Bay do not correlate well with productivity. On cruise 6, when peak algal production was measured, the organic nitrogen values did correlate well with population and production, possibly because the effect of other organic sources was overshadowed by the large algal population.

Direct nesslerization without distillation was employed in the analysis of ammonia nitrogen. This technique is now considered unsatisfactory for use on San Francisco Bay waters. Reported ammonia - nitrogen concentrations from the eight cruises commonly exceed ammonia - nitrogen concentrations measured in the estuary by others.

Because of these and other discrepancies, studies have been initiated to determine the accuracy, reproducibility and statistical variation of existing analytical and preservation techniques for the analyses of nitrogen and phosphorus forms in estuarine water.

RESULTS

A summary of data collected during the study period is presented in Appendix A. Significant trends observed have been plotted and are discussed in the following paragraphs.

Physical Data

Fresh water inflow to Suisun Bay is presented in Figure 2. These data were computed from preliminary information obtained from the U. S. Bureau of Reclamation (7). Water temperature variations are illustrated in Figure 3. These data show the temperature transition through the Bay system from the warm fresh water inflow (mean of 20.3°C) to the colder ocean waters (mean of 13.6°C at Golden Gate). Maximum temperatures at all stations were observed during the August 2, 3 sampling cruise. At stations where mid-depth samples were collected, temperatures were generally found to be the same as surface samples.

Suspended solids data were collected only from Suisun Bay during one cruise, July 16, 17, and are presented in Figure 4.

Chemical Data

Chemical data include the nitrogen series, dissolved and total phosphorus, chlorosity, dissolved silica, alkalinity and pH. Nitrogen and phosphorus data are presented in Figures 4 and 8 and discussed below with the biological data. Chlorosity and dissolved silica changes are shown in Figure 5. Alkalinity and pH data are tabulated in Appendix A. Both the mean and median pH values for all stations was 7.8 with no significant trend observed through the study area. Alkalinity expressed as mg C per liter varied from 14.0 to 29.4. These data were used in the determination of primary productivity.

As expected, chloride concentrations for a given tidal condition tend to increase through the summer with a reduction in Delta outflow. Silica concentrations were found to exceed 10 mg/l in Suisun Bay during May and June, but by early August had dropped to around 1 mg/l. A major portion of this drop is the result of increased encroachment of ocean water. A portion may be indicative of silica uptake by diatoms during the late summer.

Biological Data

Phytoplankton productivity, numbers, and kinds, were evaluated during the study period. Algal populations were determined for each surface water sample and for mid-depth samples from station 11. The intensity of productivity and population varied significantly throughout the study area. The most active zones were in Suisun Bay and the western Delta. The least active zones were in north San Francisco Bay and San Pablo Bay. Figure 6 shows a plot of the average production (expressed in milligrams of carbon fixed per cubic meter of water per hour) through the Bay portion of the study area. Figure 7 is a plot of phytoplankton productivity at all stations for cruise 6 (July 15, 16, 17) when the peak production was recorded.

As might be expected, algal populations are highest when productivity is highest, lowest when productivity is low. The predominant populations throughout the study are centric diatoms, most frequently the genera Coscinodiscus and Thalassiosira. The dominant algae in Suisun Bay during the peak production period was Skeletonema. The dominant algal genera for each sample are tabulated in Appendix A and illustrated in Appendix B. A key to the marine diatoms is provided in Appendix B.

In the chemical analyses, the inorganic nutrients available to diatoms (nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, dissolved silica and dissolved phosphorus) were measured. Organic nitrogen was also measured by direct analysis. However, since no direct determination of organic phosphorus was possible, insoluble phosphorus (the difference between total and dissolved phosphorus) was used as an indication of the organic phosphorus present. This has obvious limitations because of the large quantity of silt associated with each sample and the rapid turnover rate of phosphorus (8). Figure 4 compares the organic nitrogen, insoluble phosphorus and suspended solids data obtained from cruise 6 (July 17) in Suisun Bay. Recorded phytoplankton productivity was at its peak. As might be expected, the concentration of insoluble phosphorus closely parallels the suspended solids content and reaches a peak at about Mile 50. Except for one station, organic nitrogen follows a similar pattern.

A comparison of productivity with nitrate-nitrogen and dissolved phosphorus is presented in Figure 8. The inverse relationship of primary productivity to these nutrient forms is evident.

The most significant chemical - biological relationships observed during this study are presented in Figures 4, 6, 7 and 8. The anticipated direct relationship between phytoplankton productivity measurements and population counts is readily apparent despite the limitations in the numerical count data and analytical methods. The environmental zones and the relationship of plant nutrient concentrations to photosynthetic production are also evident.

DISCUSSION

Phytoplankton production depends on available light energy, temperature, availability of nutrients, and other environmental factors. Nutrients, particularly nitrogen and phosphorus compounds, are essential to plant life.

During the study period available nitrogen and phosphorus forms fluctuated inversely with productivity. These elements are utilized along with carbon, various trace elements, and vitamins. Dissolved silica dropped to less than 1 mg/l during the productive period in Suisun Bay. It is interesting to note that the dominant diatom in Suisun Bay during the peak production period was Skeletonema, a genus containing little silica.

Phytoplankton activity in the study area is low in comparison with many of the larger estuaries along the Atlantic coastline. Higher temperatures coupled with a longer history of fertilization from agricultural, industrial and municipal wastes may be responsible for the higher algal activities. Dissolved oxygen fluctuations attributable to algal photosynthesis and respiration damage fish production even though dissolved oxygen concentrations remain above asphyxial levels (13). Fish kills have occurred in many rivers and lakes as a result of oxygen depletions from algal respiration and decomposition (14).

The difference between nuisance conditions and an acceptable environment involves a subjective interpretation. Water quality criteria relate to water uses. Problems associated with algae or other aquatic plants may affect many uses, i.e. fishery, tastes and odors in water supplies, boating, recreation, and aesthetics.

Inorganic nitrogen and phosphorus in Suisun Bay come from numerous sources. Waste dischargers currently contribute over 5500 tons of nitrogen and 275 tons of phosphorus to Suisun Bay each year (1)(2). These nutrients may be in the inorganic form or may be converted from organic forms. The nitrogen cycle illustrated in Figure 9 illustrates the decomposition and biosynthesis processes. Inorganic nutrients are present in the fresh water inflow to the estuary owing to the geology of the stream beds as well as agricultural, industrial, and municipal activity within the tributary area.

Liebigs "law of the minimum" states that growth of a plant is dependent on the amount of foodstuff which is presented to it in minimum quantity (9). Restrictions in nutrients, light, temperature, etc. will limit production.

A second biological law, Shelfords' "law of tolerance," may be indirectly applicable. This is a law of maximums; i.e. there may be too much light, heat or nutrient material (9). An imbalance or excess of certain biological factors can create a pollution ecology. There are many examples of artificial eutrophication of lakes and estuaries from sewage and agricultural drainage (10,11, 12).

The threshold nutrient concentration required to stimulate a problem algal growth varies with the environment involved. Studies of algal blooms in 17 Wisconsin lakes report inorganic nitrogen levels of 0.30 mg/1 and inorganic phosphorus levels of 0.01 mg/1 at the start of the active growing season were found to result in subsequent algal blooms (14). The threshold nutrient level in the study area cannot be so stated unless the definition of an "algal bloom" is related to water uses. The effects of increased fertilization may be projected from analysis of other estuaries, but the break point for a given nutrient level or ratio will require much more study.

The biologically productive Suisun Bay area is the "critical zone" of the estuary. This is the region of initial mixing of fresh and ocean waters. Typically, the low-salinity zone of an estuary supports the largest numbers of phytoplankton and other fish food organisms (15). Estuaries often prove to be more productive than either the adjacent ocean or fresh-water, apparently due to the "nutrient trap" produced by the mixing of waters of different salinity and the favorable action of oscillating tidal currents in transporting nutrients, food and waste materials (9). Figure 10 presents phytoplankton productivity contours plotted against both time and distance. The consistently greater production in the Suisun Bay region (Miles 35-50) is evident from a view of a horizontal slice of the contours and the increase in production to a peak in July is evident from a similar view of a vertical slice.

Enrichment of the critical area will result in increased production to some point when light, temperature, some chemical constituent or biological predators limit further growth. Nuisance conditions may result before a limiting environmental factor is reached.

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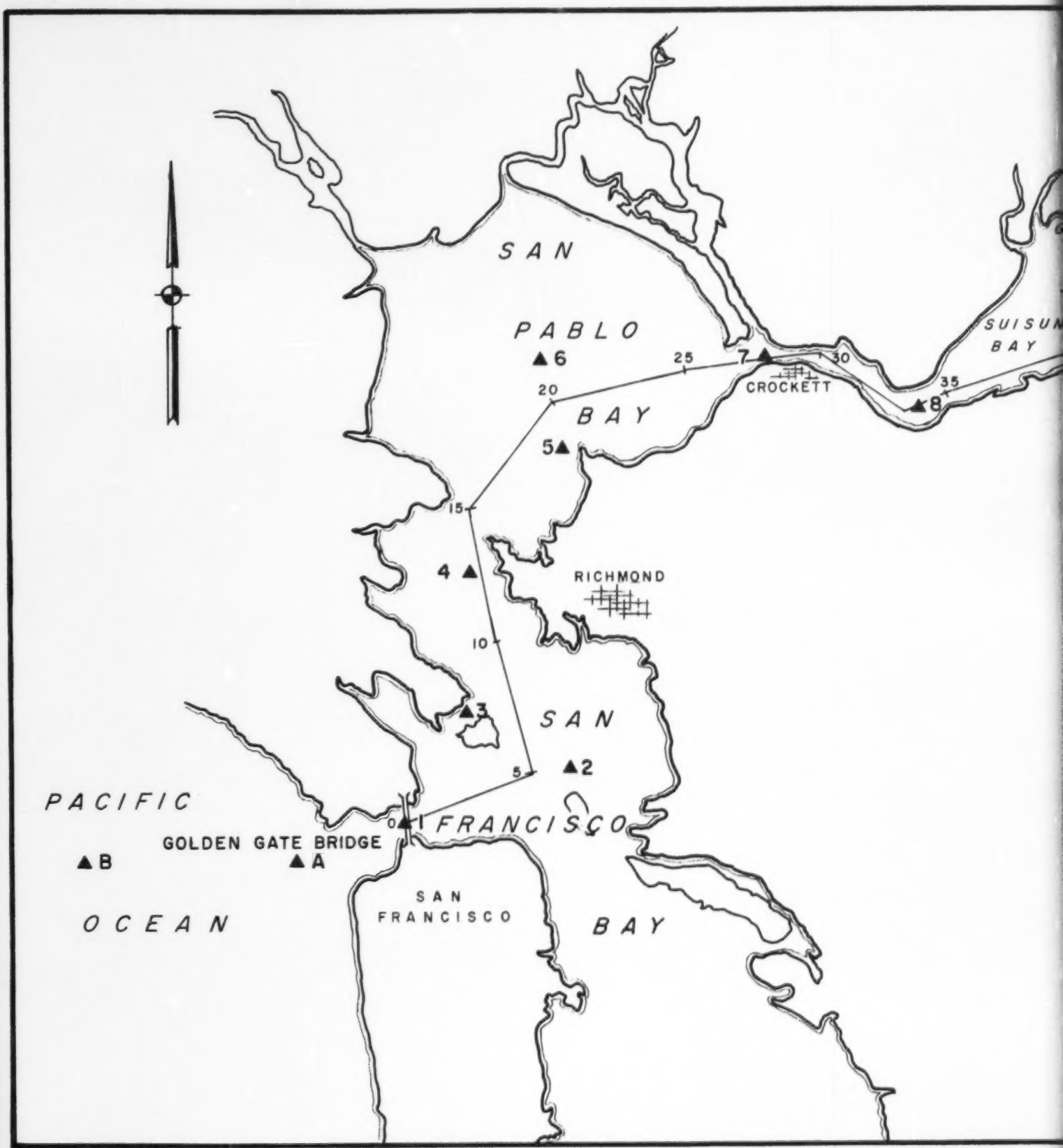
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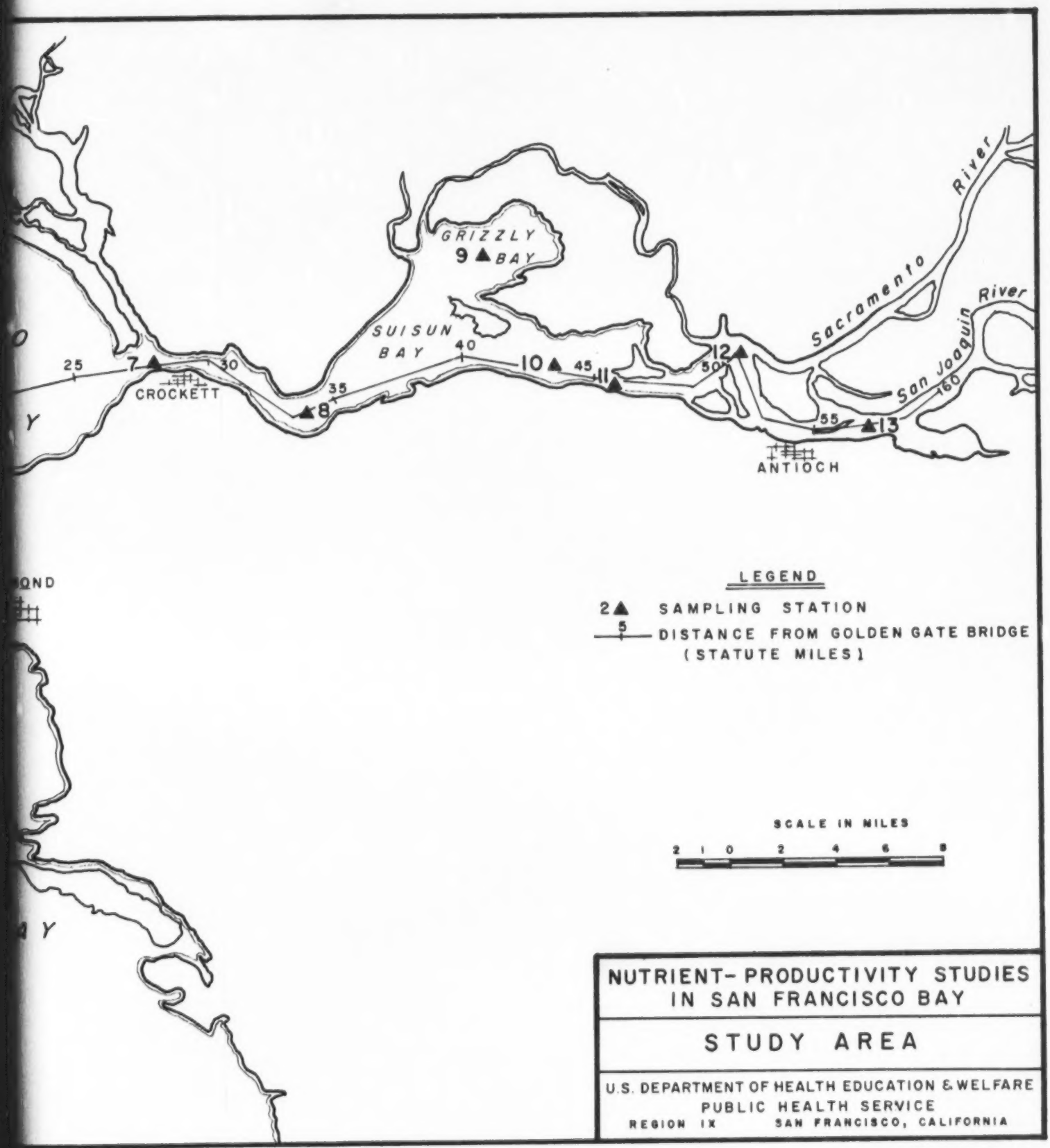

NUTRIENT-PRODUCTIVITY STUDIES IN SAN FRANCISCO BAY

STUDY AREA

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE
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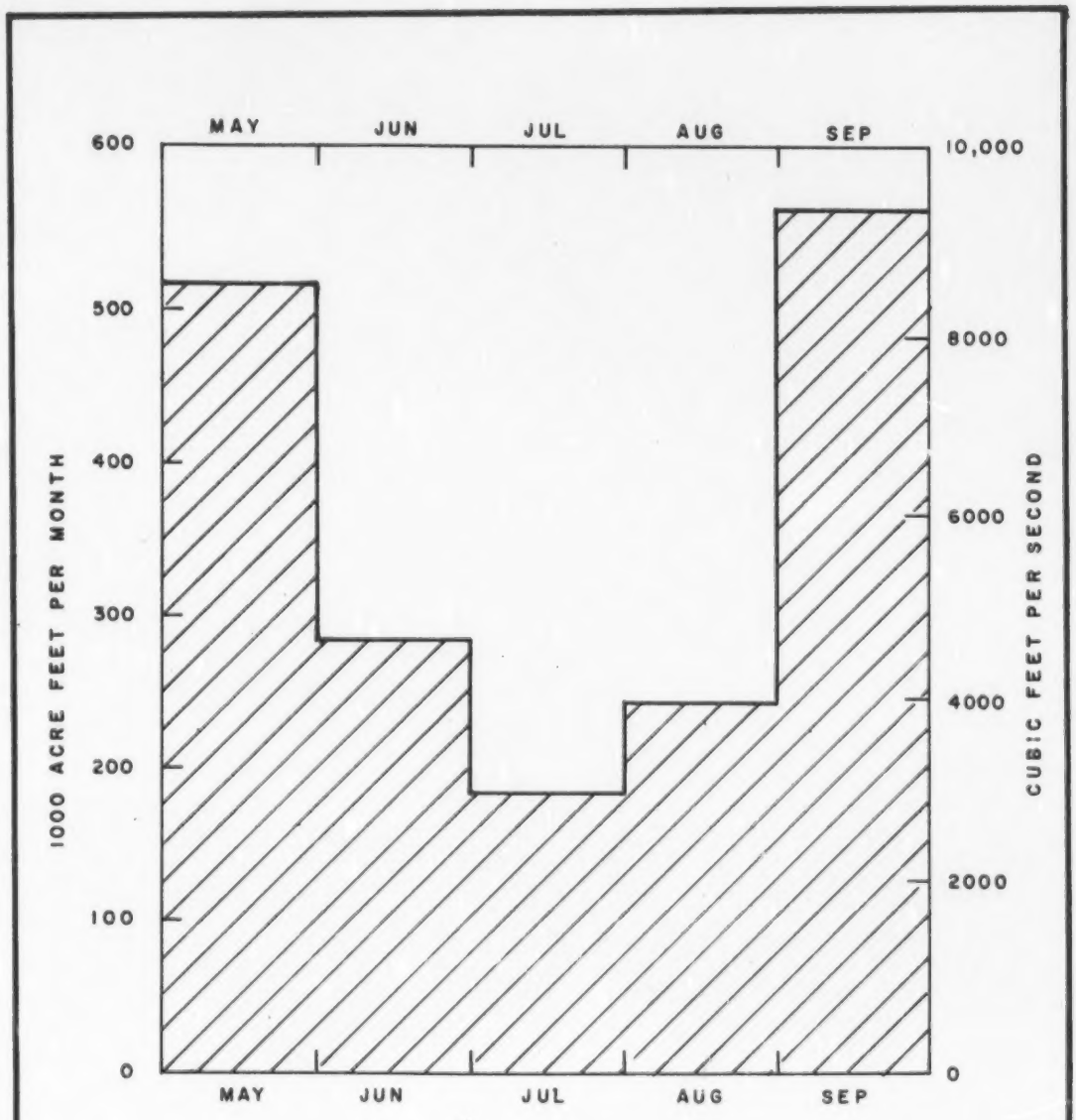
FIGURE : 1

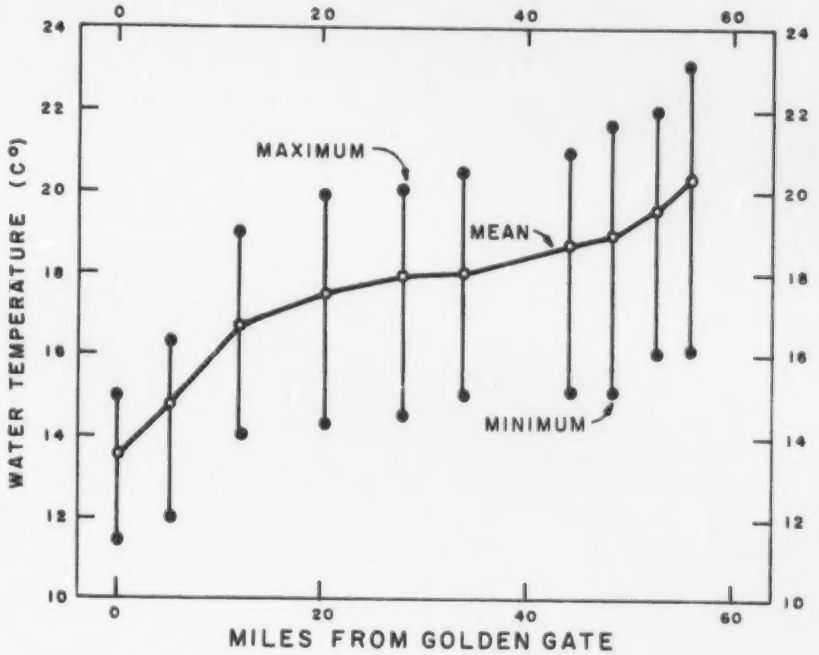


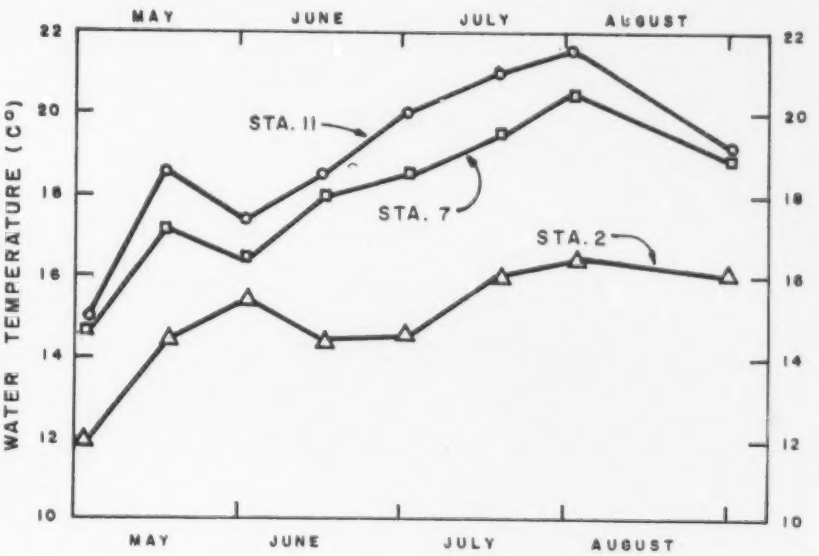
NUTRIENT PRODUCTIVITY STUDIES
IN SAN FRANCISCO BAY

DELTA OUTFLOW
(MEAN MONTHLY)

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION IX SAN FRANCISCO, CALIFORNIA

FIGURE: 2



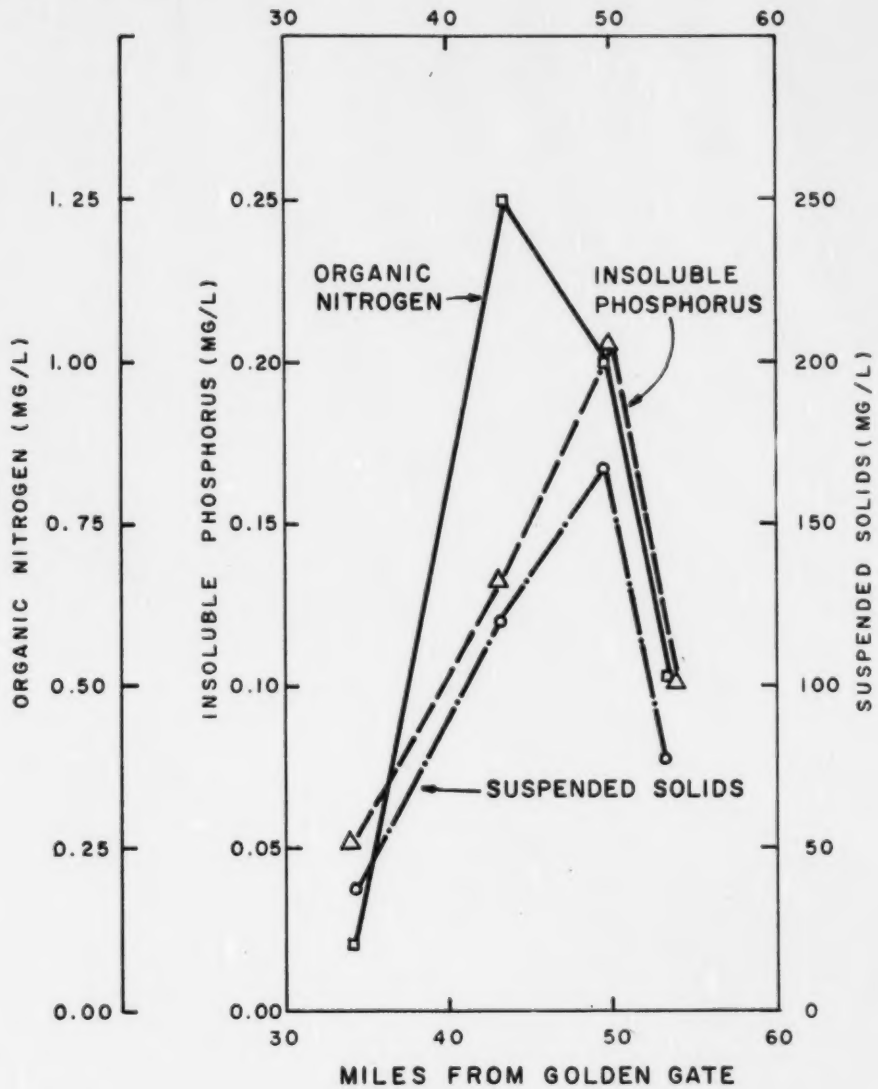


NUTRIENT PRODUCTIVITY STUDIES IN SAN FRANCISCO BAY

WATER TEMPERATURE VARATIONS

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION IX SAN FRANCISCO, CALIFORNIA

FIGURE : 3

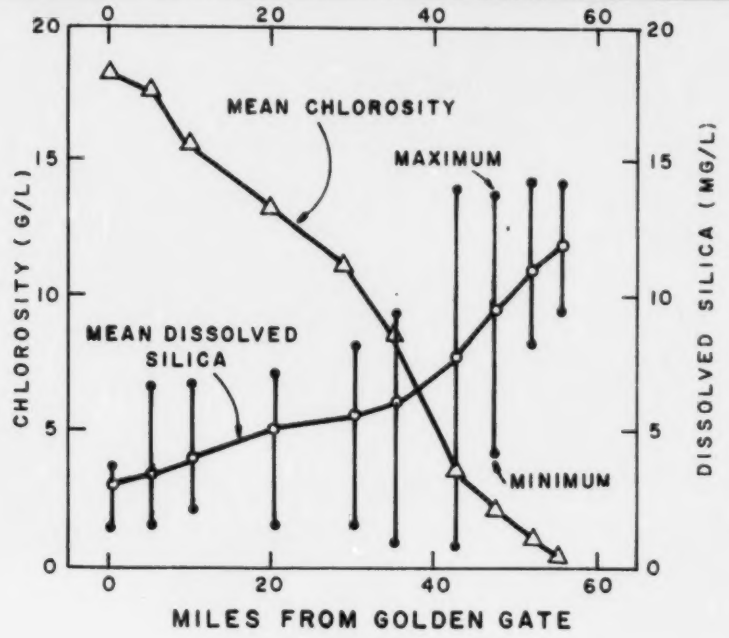


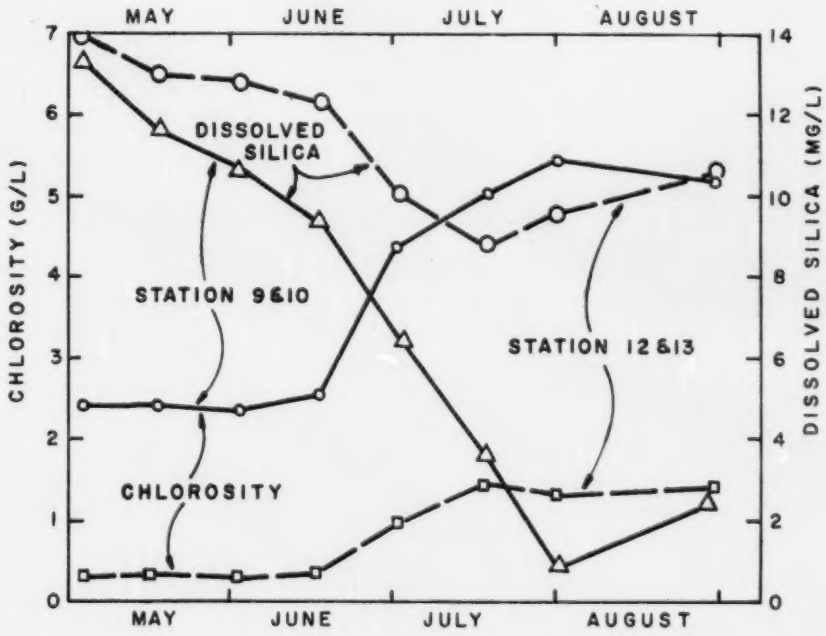
NUTRIENT PRODUCTIVITY STUDIES
IN SAN FRANCISCO BAY

PHYSICAL-CHEMICAL RELATIONSHIPS
(SUISUN BAY - CRUISE 6)

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION IX SAN FRANCISCO, CALIFORNIA

FIGURE: 4



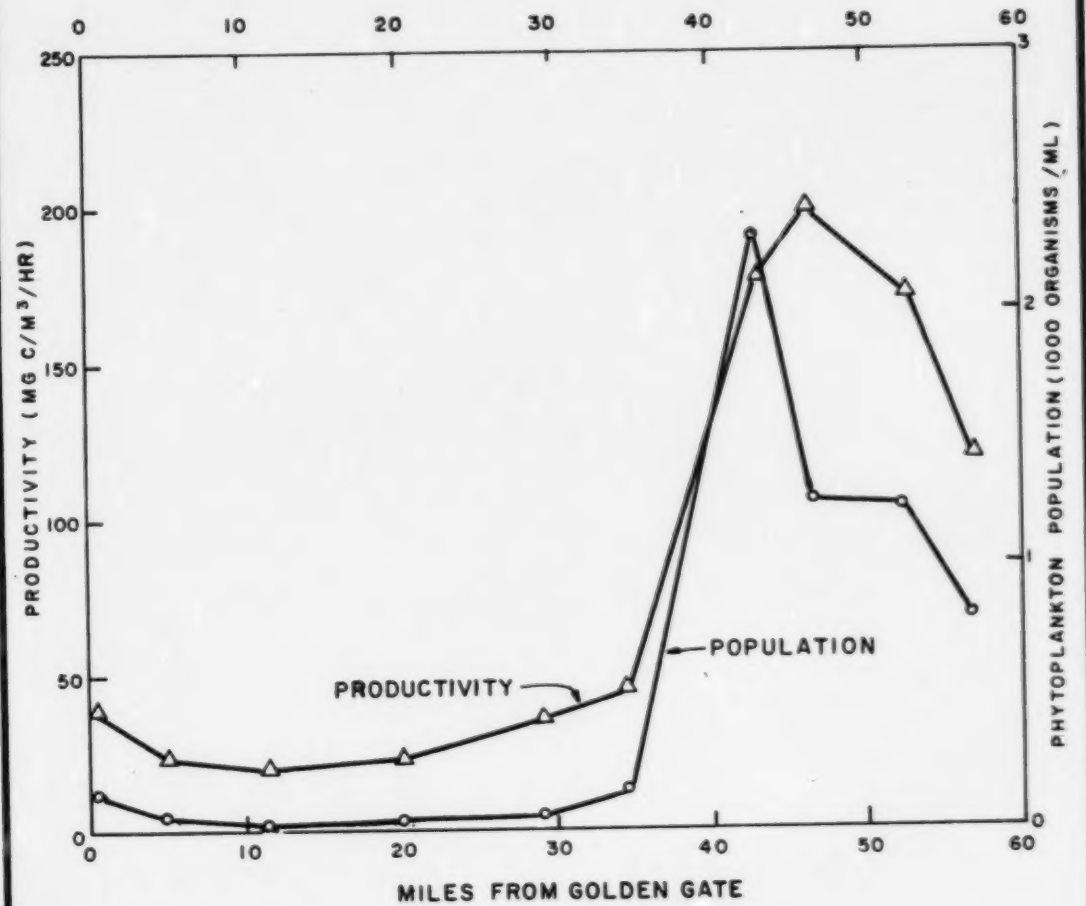


NUTRIENT PRODUCTIVITY STUDIES
IN SAN FRANCISCO BAY

CHLOROSITY & DISSOLVED SILICA VARIATIONS

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION IX SAN FRANCISCO, CALIFORNIA

FIGURE: 5

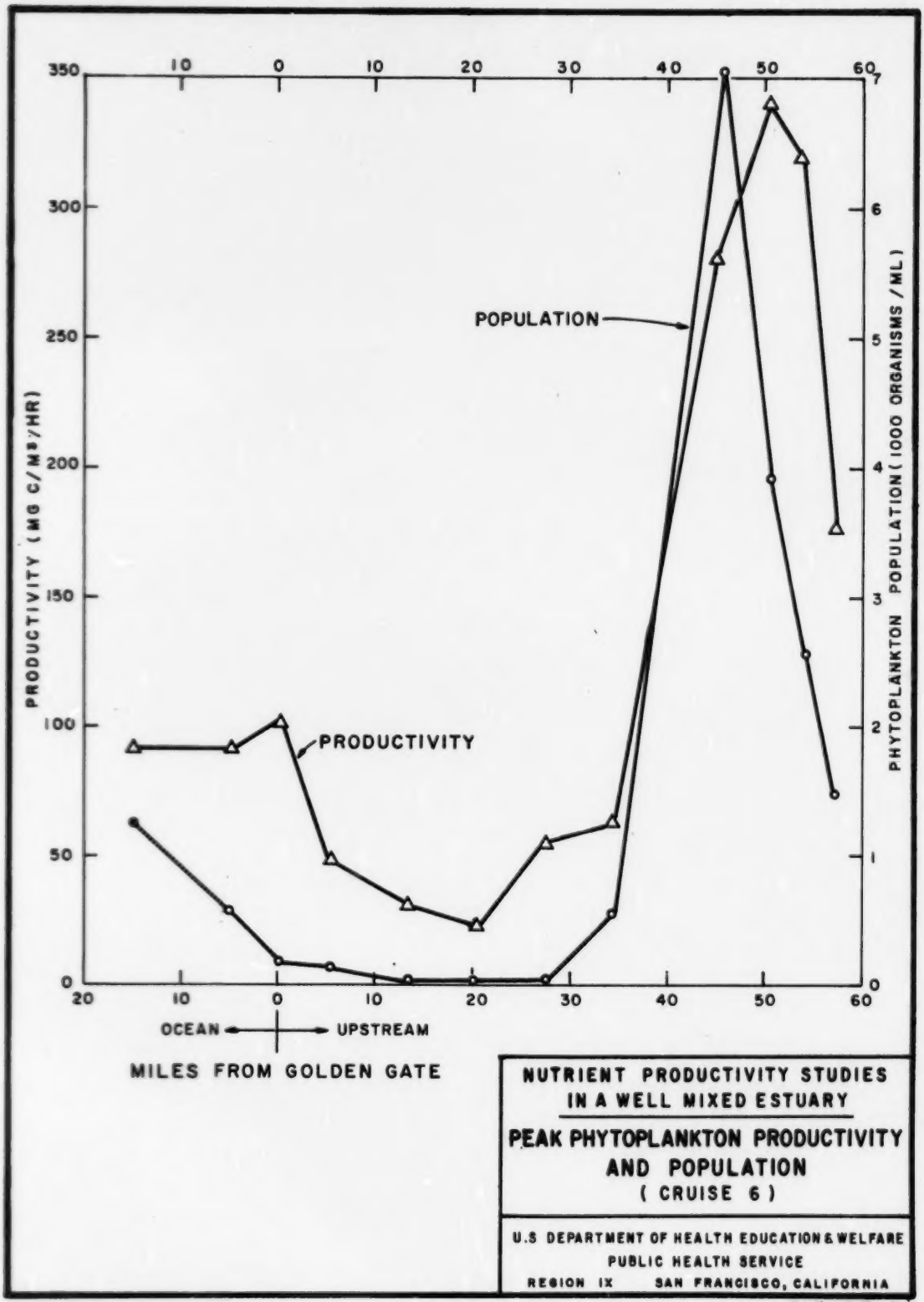


NUTRIENT PRODUCTIVITY STUDIES
IN SAN FRANCISCO BAY

MEAN PHYTOPLANKTON PRODUCTIVITY
AND POPULATION

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION IX SAN FRANCISCO, CALIFORNIA

FIGURE 6

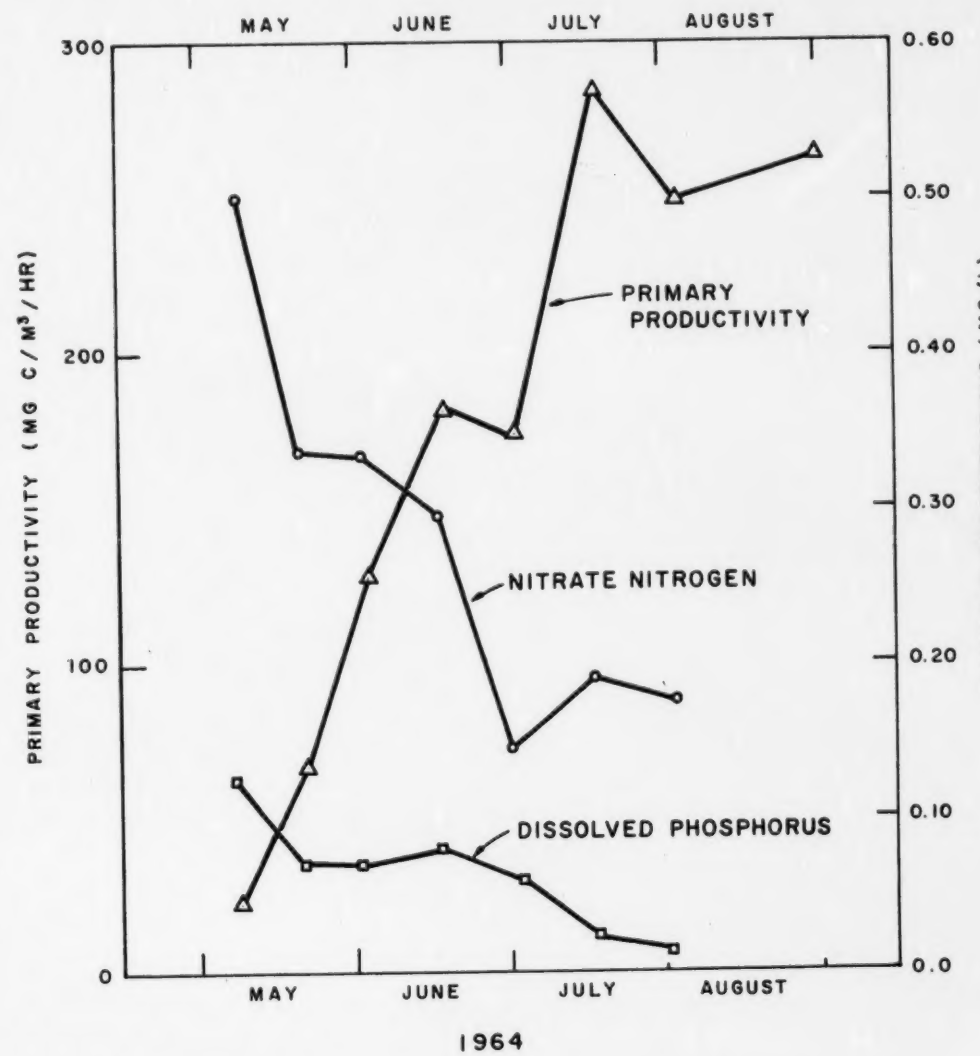


NUTRIENT PRODUCTIVITY STUDIES IN A WELL MIXED ESTUARY

PEAK PHYTOPLANKTON PRODUCTIVITY AND POPULATION
(CRUISE 6)

U.S DEPARTMENT OF HEALTH EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION IX SAN FRANCISCO, CALIFORNIA

FIGURE 7

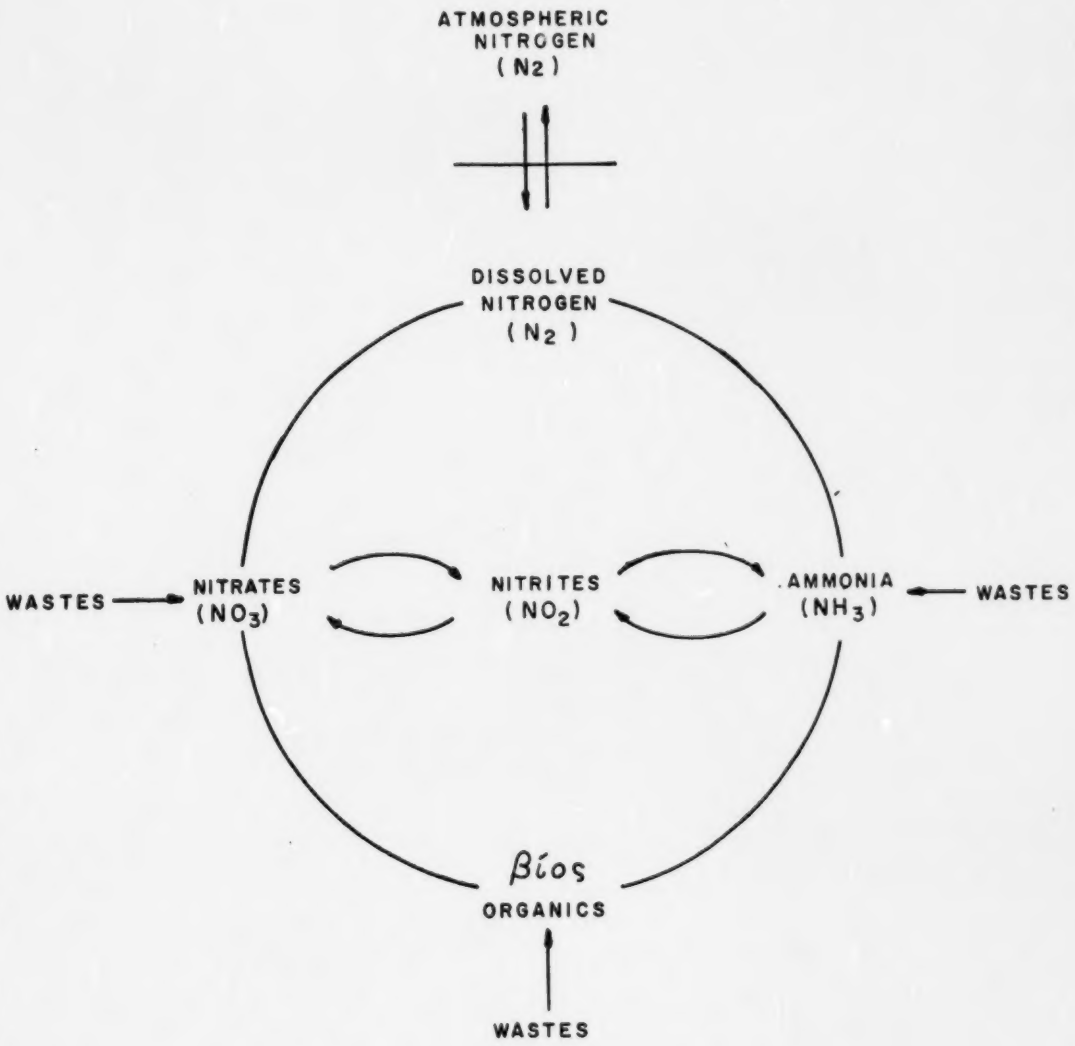


NUTRIENT PRODUCTIVITY STUDIES
IN SAN FRANCISCO BAY

NUTRIENTS AND PRODUCTIVITY
SUISUN BAY (STA. 9 & 10)

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION IX SAN FRANCISCO, CALIFORNIA

FIGURE 8

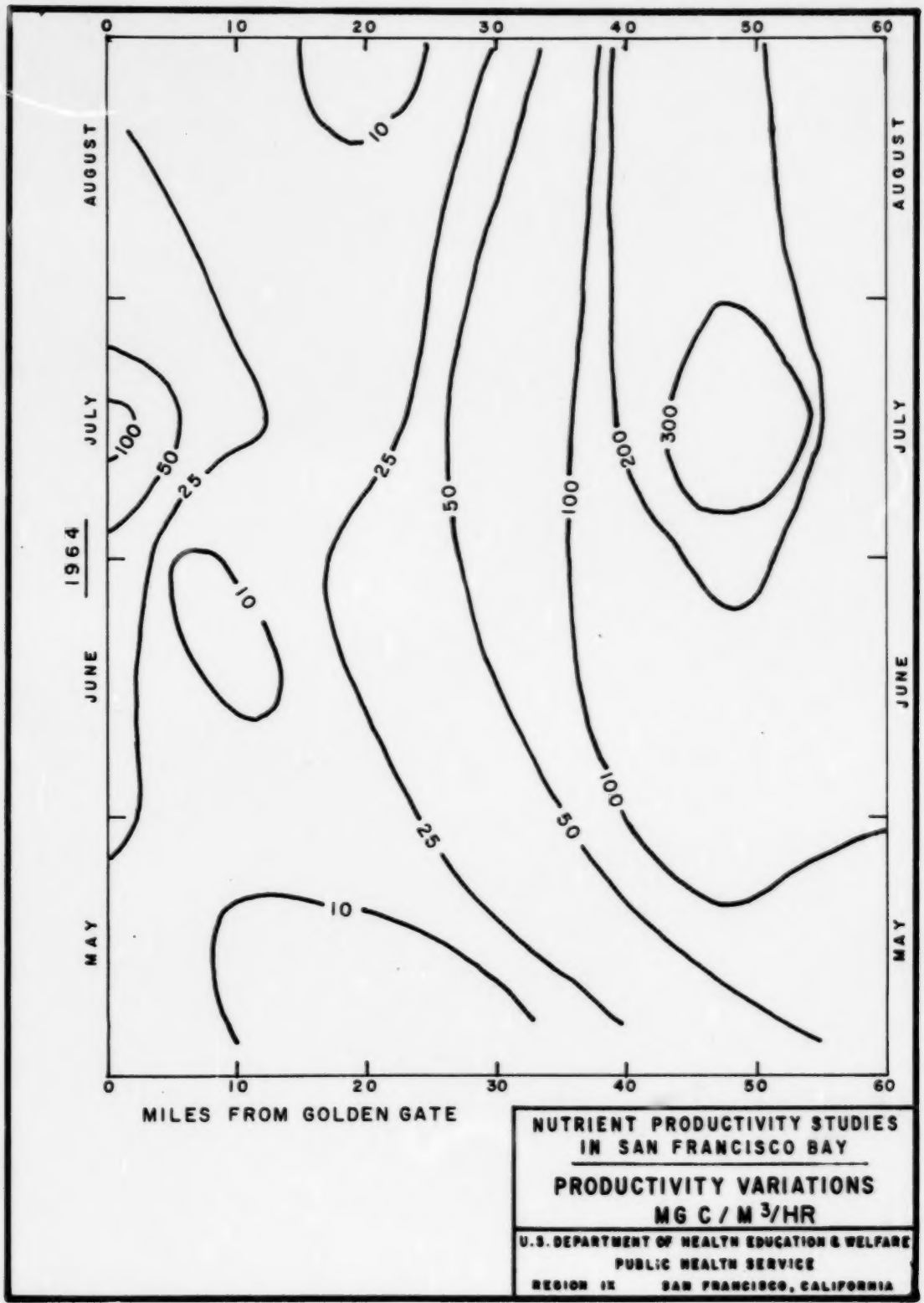


NUTRIENT PRODUCTIVITY STUDIES
IN SAN FRANCISCO BAY

NITROGEN CYCLE

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION IX SAN FRANCISCO, CALIFORNIA

FIGURE 9



NUTRIENT PRODUCTIVITY STUDIES
IN SAN FRANCISCO BAY

PRODUCTIVITY VARIATIONS
MG C / M ^{3}/HR

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION IX SAN FRANCISCO, CALIFORNIA

GPO 971-646

FIGURE 10

APPENDICES

APPENDIX A

DATA SHEETS

Bay Stations 1-13
Mid depth sample Station 11-K
Ocean Stations A & B

Code for dominant phytoplankton genera:

A	Coscinodiscus - Thalassiosira
B	Skeletonema
C	Cyclotella
D	Biddulphia
E	Chaetoceros
F	Melosira
G	Asterionella
H	Nitzschia
I	Actinoptycus
J	Pleurosigma
K	Fragilaria

Plates 1 and 2 in Appendix B contain drawings of the above diatoms.

Nutrient - Productivity Studies in San Francisco Bay

Data Sheet

Station 1

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1107	1240	1045	0925	0832	0915	1147	-
Air Temperature (°C)	14.0	14.0	16.5	15.9	12.8	13.5	15.7	-
Water Temperature (°C)	11.5	12.6	14.0	13.0	14.5	14.3	15.0	-
pH	7.7	7.7	7.8	7.8	7.8	7.8	7.8	-
Alkalinity (mgC/l)	27.2	27.2	27.5	25.4	25.3	25.5	25.6	-
Chlorosity (g/l)	18.4	18.2	17.4	18.0	18.0	18.6	19.0	-
Dissolved SiO_2 (mg/l)	3.0	2.6	3.4	3.3	3.1	2.4	1.6	-
Organic N (mg/l)	0.0	0.0	0.1	0.0	0.6	0.6	0.9	-
NH_3-N (mg/l)	0.2	0.4	0.2	0.3	0.2	0.7	0.6	-
NO_2-N (mg/l)	0.033	0.009	0.004	0.004	0.003	0.002	0.003	-
NO_3-N (mg/l)	0.33	0.30	0.26	0.28	0.15	0.33	0.24	-
Total N (mg/l)	0.563	0.709	0.564	0.584	0.953	1.632	1.743	-
Dissolved P (mg/l)	0.10	0.09	0.10	0.10	0.09	0.03	0.01	-
Total P (mg/l)	0.14	0.08	0.10	0.14	0.12	0.12	0.10	-
Productivity ($mgC/M^3/hr.$)	20.9	12.9	38.4	28.7	44.3	100.1	22.9	-
Phytoplankton (#/ml)	112	207	26	309	149	180	62	-
Dominant genera	AB	GA	AH	BA	HA	HA	HA	-

Station 2

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1032	1205	1100	0900	0800	0845	1110	1000
Air Temperature (°C)	14.0	15.0	15.8	15.8	12.4	14.4	16.0	15.5
Water Temperature (°C)	12.0	14.5	15.4	14.5	14.5	16.0	16.5	16.1
pH	7.5	7.7	7.4	7.8	7.8	7.8	7.8	7.8
Alkalinity (mgC/l)	26.9	26.6	26.2	25.2	24.5	24.6	25.1	24.8
Chlorosity (g/l)	17.4	16.9	16.9	17.1	17.5	17.8	18.2	18.1
Dissolved SiO_2 (mg/l)	3.1	3.6	3.9	6.7	3.4	3.0	1.8	3.2
Organic N (mg/l)	0.0	0.0	0.2	0.0	0.5	0.7	0.9	1.05
NH_3-N (mg/l)	0.2	0.4	0.2	0.4	0.2	0.9	0.6	0.6
NO_2-N (mg/l)	0.031	0.008	0.004	0.020	0.003	0.002	0.002	0.003
NO_3-N (mg/l)	0.33	0.31	0.27	0.36	0.22	0.33	0.30	0.29
Total N (mg/l)	0.561	0.718	0.674	0.780	0.923	1.932	1.802	1.943
Dissolved P (mg/l)	0.07	0.09	0.12	0.10	0.10	0.08	0.02	-
Total P (mg/l)	0.11	0.08	0.11	0.16	0.13	0.14	0.10	-
Productivity ($mgC/M^3/hr.$)	22.3	10.9	29.7	5.14	14.5	47.2	54.4	17.9
Phytoplankton (#/ml)	74	8	15	40	37	84	32	18
Dominant genera	AB	H	AH	A	HA	HA	HA	AB

Nutrient - Productivity Studies in San Francisco Bay

Data Sheet

Station 3

ITEM	CRUISE							
	1	2	3	4 *	5	6	7	8
Time	1053	1220	0830	0914	0815	0900	1130	1022
Air Temperature (°C)	14.0	14.0	16.0	15.5	12.5	14.0	17.0	16.0
Water Temperature (°C)	12.0	13.0	15.0	14.5	15.6	15.0	16.0	16.0
pH	7.5	7.8	7.7	6.2	7.8	7.8	7.8	7.8
Alkalinity (mgC/l)	27.0	27.2	26.6	14.9	24.9	25.1	25.4	25.0
Chlorosity (g/l)	17.7	17.9	16.1	17.0	17.7	18.3	18.4	18.5
Dissolved SiO_2 (mg/l)	5.6	2.6	3.9	4.2	3.5	3.0	1.6	2.8
Organic N (mg/l)	0.0	0.0	0.0	0.3	0.6	0.3	0.4	0.98
NH_3-N (mg/l)	0.1	0.4	0.2	0.3	0.3	1.1	0.6	0.5
NO_2-N (mg/l)	0.031	0.008	0.002	0.004	0.003	0.002	0.004	0.003
NO_3-N (mg/l)	0.32	0.26	0.28	0.25	0.21	0.28	0.29	0.25
Total N (mg/l)	0.451	0.668	0.482	0.854	1.113	1.682	1.294	1.733
Dissolved P (mg/l)	0.23	0.09	0.09	3.10	0.22	0.07	0.02	0.01
Total P (mg/l)	0.23	0.08	0.08	0.25	0.12	0.10	0.11	0.10
Productivity ($mgC/M^3/hr.$)	11.9	12.5	15.7	1.34	5.1	47.5	31.7	16.7
Phytoplankton (#/ml)	126	42	15	103	62	219	48	22
Dominant genera	GB	A	AB	H	HA	HA	HA	AH

*Contaminated

Station 4

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1140	1310	1230	0955	0912	0940	1225	1045
Air Temperature (°C)	14.0	17.0	19.0	16.0	14.0	15.0	22.2	16.2
Water Temperature (°C)	14.0	15.5	17.0	16.0	17.0	17.7	19.0	17.5
pH	7.6	7.7	7.8	7.8	7.4	7.8	7.8	7.8
Alkalinity (mgC/l)	24.6	25.6	23.9	23.4	21.5	24.0	24.5	23.9
Chlorosity (g/l)	14.0	15.7	12.4	14.7	15.9	15.4	17.2	16.6
Dissolved SiO_2 (mg/l)	5.7	4.4	6.7	4.5	3.8	3.1	2.1	3.3
Organic N (mg/l)	0.0	0.0	0.2	0.0	0.6	0.7	0.4	0.22
NH_3-N (mg/l)	0.2	0.4	0.2	0.4	0.3	0.7	0.6	0.6
NO_2-N (mg/l)	0.031	0.017	0.009	0.004	0.003	0.002	0.002	0.005
NO_3-N (mg/l)	0.41	0.35	0.36	0.36	0.25	0.39	0.28	0.37
Total N (mg/l)	0.642	0.767	0.769	0.764	1.153	1.792	1.282	1.195
Dissolved P (mg/l)	0.26	0.10	0.09	0.10	0.09	0.09	0.03	-
Total P (mg/l)	0.13	0.11	0.08	0.16	0.12	0.12	0.10	0.12
Productivity ($mgC/M^3/hr.$)	8.97	11.7	42.8	5.24	18.5	28.1	20.8	21.1
Phytoplankton (#/ml)	12	18	12	37	42	18	7	2
Dominant genera	I	A	A	AB	HA	A	HA	AI

Nutrient - Productivity Studies in San Francisco Bay

Data Sheet

Station 5

ITEM	CRUISE							
	1	2	3	4	*5	6	7	8
Time	1135	1350	1250	1015	0937	1000	1250	1110
Air Temperature (°C)	14.0	17.0	17.5	16.6	14.7	15.9	21.5	16.0
Water Temperature (°C)	14.5	16.2	17.5	18.4	18.0	18.5	20.5	18.8
pH	7.7	7.7	7.8	7.8	7.8	7.8	7.8	7.8
Alkalinity (mgC/l)	25.4	24.2	23.9	22.9	23.9	23.6	23.5	23.0
Chlorosity (g/l)	12.6	13.6	12.2	13.6	14.8	15.1	15.5	15.1
Dissolved SiO_2 (mg/l)	6.5	4.5	5.8	5.7	4.5	3.0	1.6	3.0
Organic N (mg/l)	0.0	0.1	0.7	0.0	1.4	0.7	0.6	0.98
NH_3-N (mg/l)	0.4	0.4	0.2	0.3	1.5	1.3	0.6	0.8
NO_2-N (mg/l)	0.009	0.022	0.003	0.041	0.429	0.004	0.003	0.007
NO_3-N (mg/l)	0.42	0.41	0.41	0.52	0.39	0.29	0.35	0.45
Total N (mg/l)	0.829	0.932	1.313	0.861	3.719	2.294	1.553	2.237
Dissolved P (mg/l)	0.09	0.09	0.09	0.12	0.12	0.06	0.02	-
Total P (mg/l)	0.12	0.12	0.10	0.18	0.14	0.11	0.12	0.10
Productivity ($mgC/M^3/hr.$)	7.25	13.7	40.2	28.7	18.6	25.0	16.9	8.73
Phytoplankton (#/ml)	55	33	33	56	14	30	10	13
Dominant genera	A	A	AJ	A	AH	A	A	AH

*Contaminated

Station 6

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1113	1330	1300	1022	0948	1015	-	1120
Air Temperature (°C)	15.5	17.0	19.5	15.1	14.4	16.0	-	15.2
Water Temperature (°C)	14.0	16.2	18.0	17.6	18.0	19.0	-	19.3
pH	7.8	7.7	7.7	7.9	7.9	7.8	-	7.8
Alkalinity (mgC/l)	24.2	23.4	22.9	22.7	22.1	22.7	-	22.9
Chlorosity (g/l)	11.9	12.0	11.5	11.7	12.9	13.7	-	15.0
Dissolved SiO_2 (mg/l)	6.6	6.1	6.7	5.8	4.3	3.2	-	3.2
Organic N (mg/l)	0.0	0.0	03.	0.0	0.7	0.9	-	0.54
NH_3-N (mg/l)	0.3	0.3	0.2	0.3	0.2	0.7	-	0.1
NO_2-N (mg/l)	0.009	0.017	0.004	0.002	0.002	0.002	-	0.003
NO_3-N (mg/l)	0.46	0.48	0.52	0.37	0.24	0.35	-	0.46
Total N (mg/l)	0.769	0.797	1.024	0.672	1.142	1.952	-	1.103
Dissolved P (mg/l)	0.10	0.13	0.09	0.09	0.09	0.06	-	0.03
Total P (mg/l)	0.12	0.18	0.14	0.16	0.11	0.12	-	0.10
Productivity ($mgC/M^3/hr.$)	6.98	13.6	63.1	18.2	43.9	20.0	-	10.4
Phytoplankton (#/ml)	23	19	70	28	41	18	-	7
Dominant genera	I	AJ	JF	A	AB	A	-	AB

Nutrient - Productivity Studies in San Francisco Bay

Data Sheet

Station 7

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1215	1415	1325	0940	1025	0900	1030	1040
Air Temperature (°C)	14.5	17.0	20.0	19.3	14.5	17.0	23.0	17.9
Water Temperature (°C)	14.5	17.0	17.5	17.5	19.0	19.0	20.0	19.0
pH	7.0	7.7	7.7	7.8	7.7	7.7	7.9	7.7
Alkalinity (mgC/l)	20.2	21.7	21.4	20.6	20.0	20.5	21.8	20.0
Chlorosity (g/l)	8.75	10.2	8.69	10.1	11.8	12.4	12.9	12.9
Dissolved SiO_2 (mg/l)	8.2	6.8	7.7	8.5	4.3	1.5	1.4	2.5
Organic N (mg/l)	0.5	0.2	0.0	0.0	0.5	0.7	0.7	0.58
NH_3-N (mg/l)	0.4	0.4	0.2	0.3	0.2	0.6	0.3	0.5
NO_2-N (mg/l)	0.007	0.041	0.004	0.001	0.001	0.001	0.004	0.003
NO_3-N (mg/l)	0.48	0.46	0.51	0.39	0.26	0.27	0.27	0.44
Total N (mg/l)	1.387	1.101	0.714	0.691	0.961	1.571	1.274	1.523
Dissolved P (mg/l)	0.14	0.10	0.09	0.09	0.09	0.05	0.02	0.02
Total P (mg/l)	0.15	0.10	0.14	0.25	0.12	0.08	0.09	0.08
Productivity (mgC/M^3/hr.)	6.72	23.6	44.4	31.8	49.2	50.8	44.3	18.7
Phytoplankton (#/ml)	35	48	163	43	5	30	24	44
Dominant genera	AF	JF	F	A	AB	AB	A	AB

Station 8

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1255	1215	0820	1005	0900	0915	1050	1105
Air Temperature (°C)	17.0	21.0	14.3	19.4	17.5	16.8	23.5	17.4
Water Temperature (°C)	15.0	17.2	16.5	18.0	18.6	19.5	20.5	19.0
pH	7.7	7.7	7.4	7.8	7.9	7.4	7.4	7.8
Alkalinity (mgC/l)	21.3	18.8	19.9	18.8	19.4	17.3	18.3	19.4
Chlorosity (g/l)	7.44	7.66	7.85	7.49	8.93	9.54	10.4	9.39
Dissolved SiO_2 (mg/l)	9.4	8.7	8.2	7.0	5.0	1.8	0.82	1.9
Organic N (mg/l)	0.7	0.6	0.1	0.0	0.9	0.1	0.8	0.64
NH_3-N (mg/l)	0.4	0.3	0.3	0.2	0.3	0.7	0.5	0.6
NO_2-N (mg/l)	0.012	0.008	0.003	0.001	0.003	0.003	0.003	0.004
NO_3-N (mg/l)	0.44	0.34	0.41	0.37	0.20	0.17	0.29	0.17
Total N (mg/l)	1.552	1.248	0.813	0.571	1.403	0.873	1.593	1.414
Dissolved P (mg/l)	0.09	0.08	0.10	0.09	0.09	0.04	0.01	0.02
Total P (mg/l)	0.10	0.14	0.10	0.19	0.08	0.09	0.08	0.08
Productivity (mgC/M^3/hr)	27.1	31.4	20.1	38.9	36.2	62.3	39.7	67.7
Phytoplankton (#/ml)	46	72	50	136	348	274	28	230
Dominant genera	AF	A	A	AF	AF	BA	AF	BA

Nutrient - Productivity Studies in San Francisco Bay

Data Sheet

Station 9

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1329	1235	0840	1025	0930	0935	1130	1132
Air Temperature (°C)	16.0	21.0	17.0	19.5	18.0	18.7	23.0	17.7
Water Temperature (°C)	15.0	18.0	17.0	18.3	18.8	20.5	21.0	19.0
pH	7.4	7.7	7.6	8.0	8.0	7.8	8.2	8.1
Alkalinity (mgC/l)	16.8	16.4	16.8	16.4	17.8	15.8	18.1	17.8
Chlorosity (g/l)	2.63	2.56	2.51	2.70	4.89	5.12	5.64	6.08
Dissolved SiO_2 (mg/l)	13.9	11.0	10.6	8.9	6.5	3.3	0.63	1.6
Organic N (mg/l)	0.9	0.4	0.7	0.4	0.9	1.5	1.8	0.59
NH_3-N (mg/l)	0.3	0.3	0.1	0.1	0.3	0.4	0.4	0.5
NO_2-N (mg/l)	0.008	0.009	0.002	0.002	0.000	0.002	0.002	0.002
NO_3-N (mg/l)	0.58	0.42	0.40	0.26	0.16	0.23	0.19	0.27
Total N (mg/l)	1.788	1.129	1.202	0.762	1.360	2.132	2.392	1.362
Dissolved P (mg/l)	0.16	0.08	0.07	0.08	0.06	0.01	0.01	-
Total P (mg/l)	0.18	0.20	0.14	0.20	0.18	0.17	0.12	0.12
Productivity ($mgC/M^3/hr.$)	9.21	73.1	126.	205.	168.9	276.5	248.3	284.3
Phytoplankton (#/ml)	392	848	1388	3060	2720	7620	2500	4450
Dominant genera	AF	FA	FA	AF	AF	BA	AC	BA

Station 10

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1405	1300	0900	1045	0950	1020	1200	1159
Air Temperature (°C)	14.5	21.5	16.5	21.0	18.2	18.3	23.0	15.7
Water Temperature (°C)	15.0	18.2	17.4	19.0	19.3	20.7	21.0	19.4
pH	7.7	7.7	7.6	8.0	8.0	8.1	8.1	8.0
Alkalinity (mgC/l)	17.2	15.6	16.5	16.2	17.1	17.4	17.8	17.0
Chlorosity (g/l)	2.31	2.25	2.24	2.36	3.87	5.04	5.15	4.53
Dissolved SiO_2 (mg/l)	12.7	12.3	10.9	9.8	6.3	3.9	1.0	3.2
Organic N (mg/l)	0.5	0.4	0.5	0.4	1.0	1.0	1.3	0.41
NH_3-N (mg/l)	0.3	0.3	0.1	0.2	0.2	0.3	0.2	0.6
NO_2-N (mg/l)	0.012	0.008	0.003	0.002	0.001	0.002	0.003	0.004
NO_3-N (mg/l)	0.42	0.26	0.27	0.33	0.14	0.15	0.16	0.32
Total N (mg/l)	1.232	0.968	0.873	0.932	1.341	1.452	1.683	1.334
Dissolved P (mg/l)	0.09	0.07	0.07	0.08	0.06	0.04	0.02	-
Total P (mg/l)	0.13	0.33	0.10	0.18	0.15	0.14	0.10	0.11
Productivity ($mgC/M^3/hr.$)	39.8	65.2	136.	158.	178.0	294.1	252.0	243.3
Phytoplankton (#/ml)	267	136	600	774	1255	6500	1780	3000
Dominant genera	AC	FA	FA	FB	AF	BA	AB	AB

Nutrient - Productivity Studies in San Francisco Bay

Data Sheet

Station 11

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1420	1315	0925	1100	1000	1040	1215	1215
Air Temperature (°C)	17.0	22.0	17.3	20.5	18.4	20.5	23.0	17.0
Water Temperature (°C)	15.0	18.5	17.4	18.5	20.0	21.0	21.5	19.2
pH	7.6	7.7	7.1	8.1	7.9	8.1	8.0	8.0
Alkalinity (mgC/l)	15.7	15.5	14.2	15.8	16.6	16.8	17.1	16.8
Chlorosity (g/l)	1.22	1.35	1.06	1.33	2.49	3.37	3.81	3.73
Dissolved SiO_2 (mg/l)	13.9	13.6	13.0	10.5	8.1	6.1	4.1	4.9
Organic N (mg/l)	0.6	0.4	0.5	0.9	0.5	0.8	1.1	0.23
NH_3-N (mg/l)	0.3	0.2	0.1	0.2	0.1	0.2	0.6	0.4
NO_2-N (mg/l)	0.010	0.007	0.002	0.002	0.001	0.004	0.003	0.003
NO_3-N (mg/l)	0.35	0.24	0.23	0.18	0.14	0.30	0.25	0.44
Total N (mg/l)	1.260	0.847	0.832	1.282	0.741	1.304	1.953	1.073
Dissolved P (mg/l)	0.13	0.05	0.06	0.06	0.05	0.03	0.02	0.01
Total P (mg/l)	0.20	0.16	0.10	0.23	0.18	0.23	0.14	0.20
Productivity ($mgC/M^3/hr.$)	28.4	108.5	146.	133.	266.6	341.9	298.5	192.5
Phytoplankton (#/ml)	165	284	952	1510	1875	3940	2780	600
Dominant genera	FA	AF	AF	AF	AF	BA	AB	BA

Station 11-K (Mid Depth)

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1420	1315	0925	1100	1000	1040	1215	1215
Air Temperature (°C)	-	-	-	-	-	-	-	-
Water Temperature (°C)	14.8	-	17.6	17.5	19.3	21.1	21.5	19.2
pH	-	-	-	-	-	-	-	-
Alkalinity (mgC/l)	-	-	-	-	-	-	-	-
Chlorosity (g/l)	-	-	-	-	-	-	-	-
Dissolved SiO_2 (mg/l)	-	-	-	-	-	-	-	-
Organic N (mg/l)	0.5	-	0.6	1.0	1.2	1.2	1.0	0.29
NH_3-N (mg/l)	0.3	-	0.1	0.1	0.2	0.4	0.6	0.4
NO_2-N (mg/l)	0.010	-	0.002	0.003	0.001	0.002	0.001	0.003
NO_3-N (mg/l)	0.36	-	0.26	0.16	0.16	0.30	0.36	0.53
Total N (mg/l)	1.170	-	0.962	1.263	1.561	1.902	1.961	1.223
Dissolved P (mg/l)	0.08	-	0.06	0.07	0.06	0.01	-	0.00
Total P (mg/l)	0.13	-	0.10	0.16	0.30	0.27	0.16	0.20
Productivity ($mgC/M^3/hr.$)	-	-	-	-	-	-	-	-
Phytoplankton (#/ml)	201	-	332	368	938	735	3360	1430
Dominant genera	AF	-	AF	AF	AF	AF	AFB	BAF

Nutrient - Productivity Studies in San Francisco Bay

Data Sheet

Station 12

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1438	1335	0945	1120	1020	1102	1245	1232
Air Temperature (°C)	19.0	22.0	17.0	21.0	19.3	21.1	23.0	18.0
Water Temperature (°C)	16.0	18.8	18.0	19.0	20.2	21.6	22.0	20.5
pH	7.5	7.6	7.5	8.0	7.9	8.0	7.9	7.8
Alkalinity (mgC/l)	14.6	14.9	15.5	15.6	16.2	16.3	16.2	16.3
Chlorosity (g/l)	0.51	0.56	0.47	0.57	1.40	2.18	2.09	2.13
Dissolved SiO_2 (mg/l)	14.1	13.5	12.7	12.1	9.4	8.1	8.2	8.9
Organic N (mg/l)	0.6	0.4	0.6	0.5	0.7	0.5	1.2	0.79
NH_3-N (mg/l)	0.2	0.3	0.1	0.2	0.1	0.2	0.6	0.3
NO_2-N (mg/l)	0.008	0.006	0.004	0.002	0.002	0.002	0.003	0.003
NO_3-N (mg/l)	0.14	0.15	0.13	0.08	0.06	0.18	0.20	0.39
Total N (mg/l)	0.948	0.856	0.834	0.782	0.862	0.882	2.003	1.483
Dissolved P (mg/l)	0.05	0.06	0.06	0.05	0.06	0.03	0.02	0.20
Total P (mg/l)	0.10	0.14	0.08	0.12	0.11	0.13	0.10	0.19
Productivity (mgC/M^3/hr.)	62.0	45.0	166.	172.	148.1	321.0	198.2	225.2
Phytoplankton (#/ml)	347	604	1060	925	753	2550	1585	2330
Dominant genera	AC	AC	AF	AF	AF	AF	AF	AF

Station 13

ITEM	CRUISE							
	1	2	3	4	5	6	7	8
Time	1500	1440	1005	1150	1040	1130	1315	1302
Air Temperature (°C)	20.0	24.0	17.0	21.0	22.0	24.0	25.5	18.0
Water Temperature (°C)	16.0	19.3	18.5	20.0	21.6	23.1	23.0	21.0
pH	7.4	7.4	7.3	7.9	7.8	8.0	7.8	7.8
Alkalinity (mgC/l)	14.6	14.5	15.1	15.6	16.0	15.8	15.7	15.7
Chlorosity (g/l)	0.15	0.12	0.12	0.17	0.48	0.80	0.51	0.72
Dissolved SiO_2 (mg/l)	14.1	12.6	13.0	12.6	10.6	9.3	10.8	12.3
Organic N (mg/l)	0.5	0.2	0.5	0.9	0.4	1.0	0.8	0.45
NH_3-N (mg/l)	0.3	0.2	0.1	0.5	0.2	0.1	0.3	0.3
NO_2-N (mg/l)	0.008	0.005	0.003	0.002	0.005	0.003	0.003	0.004
NO_3-N (mg/l)	0.09	0.06	0.07	0.06	0.02	0.10	0.15	0.17
Total N (mg/l)	0.898	0.465	0.673	1.462	0.625	1.203	1.253	.924
Dissolved P (mg/l)	0.08	0.03	0.03	0.05	0.04	0.02	0.02	0.01
Total P (mg/l)	0.06	0.06	0.06	0.12	0.07	0.08	0.09	0.09
Productivity (mgC/M^3/hr.)	50.2	40.4	137.	135.	-	176.6	143.7	143.1
Phytoplankton (#/ml)	378	264	894	687	1090	1490	1250	686
Dominant genera	AK	AF	AC	AC	AF	AF	AF	AB

Nutrient - Productivity Studies in San Francisco Bay

Data Sheet

Station A

ITEM	CRUISE 1	2	3	4	5	6	7	8
Time		-		0910		0900		
Air Temperature (°C)		-		16.1		18.3		
Water Temperature (°C)		-		12.2		16.1		
pH		7.8		7.8		7.89		
Alkalinity (mgC/l)		27.4		25.5		25.4		
Chlorosity (g/l)		18.7		18.4		18.7		
Dissolved SiO_2 (mg/l)		2.4		3.0		2.4		
Organic N (mg/l)		0.5		0.0		0.7		
NH_3-N (mg/l)		0.4		0.2		0.3		
NO_2-N (mg/l)		0.022		0.004		0.003		
NO_3-N (mg/l)		0.22		0.36		0.35		
Total N (mg/l)		1.142		0.514		1.353		
Dissolved P (mg/l)		0.08		0.07		0.07		
Total P (mg/l)		0.06		0.12		0.11		
Productivity ($mgC/M^3/hr.$)		4.0		4.11		81.8		
Phytoplankton (#/ml)		324		65		528		
Dominant genera		EG		HB		HA		

Station B

ITEM	CRUISE 1	2	3	4 *	5	6	7	8
Time		-		1020		1140		
Air Temperature (°C)		-		14.4		18.3		
Water Temperature (°C)		-		10.0		16.7		
pH		7.8		7.9		8.3		
Alkalinity (mgC/l)		29.4		25.9		26.4		
Chlorosity (g/l)		20.7		19.1		19.5		
Dissolved SiO_2 (mg/l)		1.4		2.6		0.53		
Organic N (mg/l)		0.4		0.0		1.2		
NH_3-N (mg/l)		0.4		6.2		0.9		
NO_2-N (mg/l)		0.020		0.004		0.001		
NO_3-N (mg/l)		0.18		0.34		0.03		
Total N (mg/l)		1.000		-		2.131		
Dissolved P (mg/l)		.003		0.06		0.01		
Total P (mg/l)		0.03		0.10		0.03		
Productivity ($mgC/M^3/hr.$)		0.41		0.17		82.2		
Phytoplankton (#/ml)		262		31		1257		
Dominant genera		AG		HB		EHG		

* Contaminated

APPENDIX B

Marine Diatoms, (Key to the Genera)

Phytoplankton Plates (from "Phytoplankton of Chesapeake Bay" by Ruth E. Griffith).

MARINE DIATOMS*

Key to the Genera

A. Outline of the Valves Circular; cells either cylindrical or disc-shaped.

B. Processes many times larger than cell diameter.

C. Cells united into chain-like colonies by means of their setae.

D. Setae 2 per valve, arising opposite each other. CHAETOCEROS

DD. Setae 6 or more per valve. BACTERIASTRUM

CC. Cells connected for a short time immediately after cell division, otherwise solitary.

E. Valves each with numerous processes arranged crown-like on the edge. CORETHRON

EE. Valves each with only one process.

F. Valves with process centrally placed on the flat surface. DITYLUM

FF. Valves more or less obliquely pointed to form a spine. RHIZOSOLENIA

BB. Processes none or not decidedly longer than cell diameter.

G. Cells united in chains in which the walls of the adjacent cell rest directly upon each other and are united.

H. Adjacent cells united by a silicated rim of tubes or needles parallel to the axis of the chain.

I. Valves having a definite net-like areolated structure, large. STEPHANROPYXIS

II. Valves without definite structure, small. SKELETONEMA

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* H.H. Gran (University of Oslo) and E.C. Angst (University of Washington) Plankton Diatoms of Puget Sound, 1931.

HH. Adjacent cells of the chain united by a large part of the valvar surface or by means of short blunt projections.

J. Length of cell normally not greater than the diameter, or at most one and half times as long.

K. Girdle zone with a number of ring-shaped copulae; valve with spinules secreting mucilage, thin. LAUDERIA

KK. Valves without spinules, thick.

L. Valves without or with barely visible markings, cylindric to semi-spherical, without keel-like projections at the edge. MELOSIRA

LL. Valves with decided markings, and with keel-like projection on the edge. PARALIA

JJ. Length of the cell more than one and one half times that of its diameter; copulae present but often indistinct.

M. Valves with 2 flat projections on each valve by which the cells are held together. CERATAULINA

MM. Valves with one little excentric spine which passes into a depression in the adjacent cell. RHIZOSOLENIA

MMM. Valves without spines; cells cylindric with flat ends.

N. Girdle zone without visible structure; cell wall collapsing when dried LEPTOCYLINDRUS

NN. Girdle zone with visible copulae shaped like open rings. DACTYLIOSOLEN

GG. Cells solitary or united into colonies by means of mucilage strands or masses.

O. Cells united by means of mucilage strands; valves each with one or more copulae.

P. Cells united into chains by means of 4 to 8 subcentral mucilage strands COSCINSIRA

PP. Cells united into chains by mean of a central mucilage strand or irregularly arranged in a mucilaginous mass. THALASSIOSIRA

PPP. Cells touching each other with the central part of valves; mucilage secreting spinules distributed over the whole surface of the valve. LAUDERIA

OO. Cells solitary.

Q. Cells cylindrically elongated, at least twice as long as their diameter.

R. Valves with an excentric tip or at least with a little excentric process. RHIZOSOLENIA

RR. Valves without an excentric tip.

S. Valves each with a central spine and a crown of small needle-like spines at the rim. DITYLUM

SS. Valves without central spines, each with two low blunt projections at the rim. CERATAULINA

QQ. Cells short, cylindrical or disc-shaped, height smaller than their diameter.

T. Valve with a winglike expansion around the margin. PLANKTONIELLA

TT. Valve without such wing.

U. Valves with a star-like structure, with 5-9 transparent elevated rays radiating from a central area; rest of valve surface areolated. ASTEROMPHALUS

UU. Valve without such structure.

V. Valves strongly radially bulged, divided into regular alternating sectors. ACTINOPTYCHUS

VV. Valves not or only slightly radially bulged.

W. Valves each with one smooth eye near the edge, and often with marginal spinules, structure clearly radially punctate, not areolate. ACTINOCYCLUS

WW. Valves with 4 or more conical processes regularly distributed near the margin. AULACODISCUS

WWW. Valves without marginal eye and conical processes, sometimes with marginal spinules of different size.

X. Valve structure very fine; central area differentiated from the marginal zone; chromatophores elongated HYALODISCUS

XX. Valve structure more or less clear; chromatophores round, plate-like.

Y. Valve with circular central area surrounded by radiating and concentric ribs between which areolae are visible. ARACHNOIDISCUS

YY. Valves without radiating ribs; central area if present, with irregular outline. COSCINODISCUS

AA. Outline of the valves not exactly circular, 3-4 angled or elliptical.

b. Outline of valves 3-4 angled

c. Cells solitary; spine 1 per valve, central DITYLUM

cc. Cells in chains; spines none or more than one per valve. BIDDULPHIA

bb. Outline of valves not 3-4 angled; valves long-elliptical, bilaterally symetrical.

d. Valves ending in an excentric spine. RHIZOSOLENIA

dd. Valves not ending in an excentric spine, flat or vaulted in the middle.

e. Valve projection ending in long setae. CHAETOCEROS

ee. Valve prjections not ending in long setae, either pointed or truncate.

f. Cells in spiral chains; axis of spiral paralled to the transapical axis; projections truncate. EUCAMPIA

ff. Cells in straight cylindrical chains; valve projections truncate, very low; cell wall thin, weakly silicated. CERATAULINA

fff. Cells single or in straight or zig zag chains; projections various; cell walls silicated with distinct structure on the valves and often also on the girdle. BIDDULPHIA

AAA. Outline of valves linear or lanceolate, without processes or spinules.

g. Cells in immotile band-like chains; chromatosphores 1-2 per cell. FRAGILARIA

gg. Cells solitary or united into variously shaped colonies.

h. Valve with normal raphe and central nodule.

i. Raphe straight, or placed in the margin or a median keel.

j. Valve boat shaped, with a median keel. TROPIDONEIS

jj. Valve flat without keel. NAVICULA

ii. Raphe slightly S-shaped. PLEUROSIGMA

hh. Valve with raphe, but without central nodule. NITZSCHIA

hhh. Valve without raphe, linear or tichken at one end than other.

k. Two ends of cell approximately alike. THALASSIOTHRIX

kk. Two ends of cell dissimilar, cells in spiral colonies. ASTERIONELLA

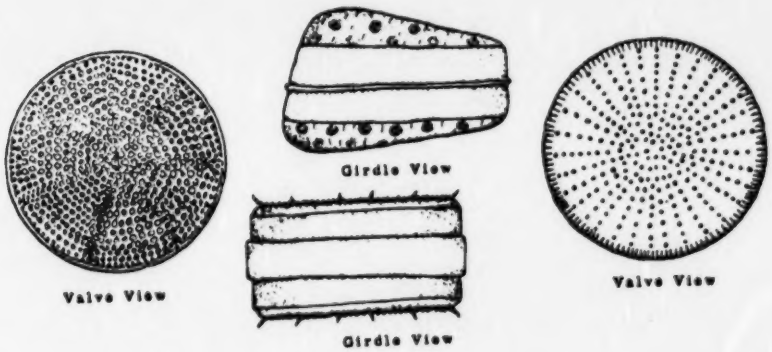
Definitions

Process - an extension of a cell or cell wall - a horn arm or abrupt protusion from a plane surface.

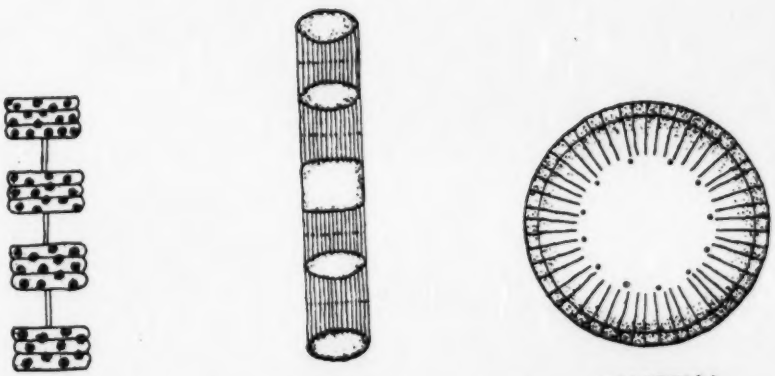
Seta - a hair - usually arising from within a cell.

Raphe - a longitudinal canal within a wall of diatoms belonging to the Penales, forming a median line on one or both sides of the diatom shell.

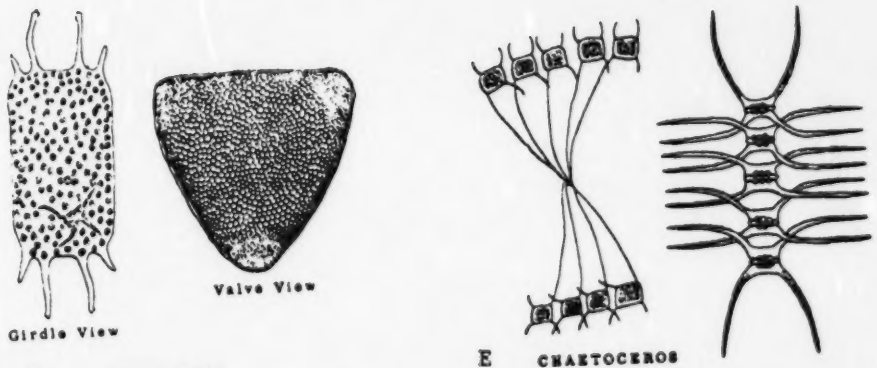
PLATE I



A COSCINODISCUS



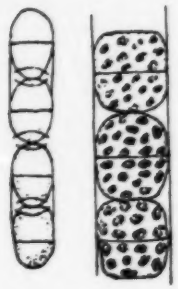
A THALASSIOSIRA B SKELETONEMA C CYCLOTELLA



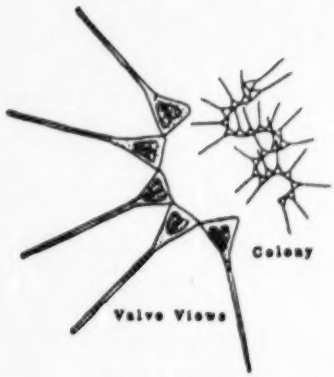
D BIDDULPHIA

E CHAETOCEROS

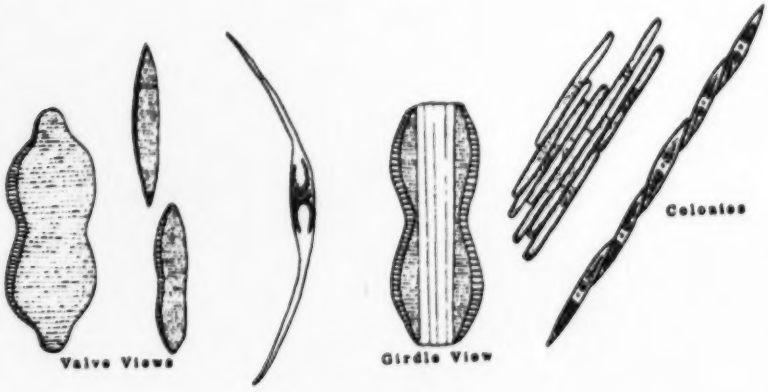
PLATE 2



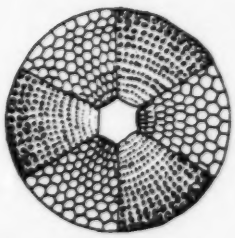
F MELOSIRA



G ASTERIONELLA

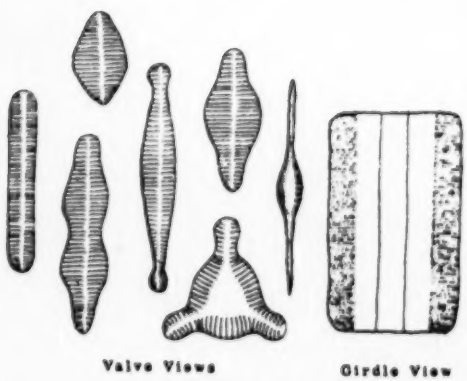


H NITZSCHIA



I ACTINOPTYCHUS

J PLEUROSIGMA



K FRAGILARIA